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SUMMARY

Problem.

Operations Desert Shield and Desert Storm placed U.S. military personnel in a hot environment and required personnel to perform strenuous activity, sometimes while wearing chemical defense ensemble. Heavy work load during high heat conditions while wearing chemical defense gear has been shown to cause heat stress within 30 minutes. A solution would be to provide individual microclimate cooling apparel. The effectiveness of a "cooling suit" needs to be evaluated by its ability to affect various physiological functions and by its effect on subjective comfort.

Objectives.

The objectives of this study were to evaluate whether a cooling suit would lower subjective ratings of perceived exertion (RPE), lower heart rate (HR), and whether wearing a cooling suit would reduce the magnitude of the correlation between RPE and HR. To address these objectives, subjects were tested during exercise, wearing chemical defense ensemble, under four different combinations of ambient heat level and exercise intensity conditions.

Approach.

Thirty-one U.S. Marine Corps volunteer subjects, wearing chemical defense ensemble, were tested in four separate heat/exercise combinations during both cooling suit and control sessions. Microclimate cooling was provided by a portable active ice system, EXOTEMP CD-22. In experimental Condition 1, hot temperature and hard exercise, eight subjects were tested on two separate days during control and cooling suit sessions in a heat chamber at 120°F, 20% relative humidity (RH), on a 3.0 miles per hour (mph) treadmill walk at a 2% grade. In experimental Condition 2, warm temperature and hard exercise, seven different subjects were tested in separate control and cooling suit sessions at 90°F, 35% RH, at the same treadmill speed and grade as described in Condition 1. In experimental Condition 3, hot temperature and easy exercise, eight more subjects were tested during control and cooling suit sessions with the chamber heated to 120°F, 20% RH, on a 1.8-mph treadmill walk at a 0% grade. In

experimental Condition 4, warm temperature and easy exercise, a group of eight subjects was tested in a control and a cooling suit session with the chamber heated to 90°F, 35% RH, on a 1.8-mph treadmill walk at a 0% grade.

Results.

During conditions of high heat and hard exercise, RPE was significantly lower for subjects wearing a microclimate cooling suit. Mean HR was also lower during the cooling suit session when compared to the control session, and this difference approached statistical significance. Under less severe heat and exercise conditions, RPE was not significantly lowered by wearing a microclimate cooling suit; however, HR was statistically significantly lowered during cooling suit sessions. The magnitude of the Pearson correlation between RPE and HR was lower during sessions in which a microclimate cooling suit was worn.

Conclusions.

It appears that Borg's assertion that RPE is an acceptable substitute for physiological measures of exertion may need to be reexamined in conditions of exercise in heat when wearing a microclimate cooling suit. The observed decrease in the magnitude of Pearson correlations between RPE and HR indicate that a cooling suit will interfere with subjective perception of exertion.

INTRODUCTION

Operations Desert Shield and Desert Storm placed U.S. military personnel in a hot environment in which they were required to perform strenuous activity, sometimes while wearing chemical defense ensemble. During the summer months of July and August, it is not unusual for the Saudi Arabian desert to reach ambient temperatures of 120°F. Under these conditions, an individual wearing chemical defense equipment, backpack, and carrying an M-16 rifle could be adversely affected by heat stress within 30 minutes (Banta, Pozos, Sucec, and Trone, 1992). Current studies at the Naval Health Research Center (NHRC) show that a heavy work load during high heat conditions will cause cardiac strain as well as elevated core temperature and mean skin temperature.

A symptom of these physiological effects is a decrement in cognitive functioning. Grether (1973) reported that human performance of such tasks as time estimation, reaction time, vigilance, tracking, and other skilled cognitive operations decline in ambient temperatures above 85°F.

To relieve heat stress, one solution would be to provide individual cooling; this could be accomplished by providing a military personnel with some form of controlled microclimate. Most of the attempts to provide microclimate cooling have been achieved by circulating cool water or air through plastic tubes, either in a hood, the liner of a helmet, or in a body garment (Brooks, Hynes, Bowen, Allen, and Kuehn, 1981; Shapiro, Pandolf, Sawka, Toner, Winsman, and Goldman, 1982; Nunneley and Maldonado, 1981; Pimental, Janik, and Avellini, 1988; Williams and Shitzer, 1974). Generally, the results of such controlled microclimate cooling studies have shown markedly reduced heat strain, heart rate, blood pressure, core temperature, and state of dehydration (Gold and Zornitzer, 1968; Froese and Burton, 1957; Kissen, Hall, and Klemm, 1971; Nunneley, Troutman, and Webb, 1971).

Not only should the effectiveness of a cooling suit be measured by its ability to affect various physiological functions (e.g., heart rate, core temperature, mean skin temperature) but also by its effect on subjective comfort. One such measure of subjective comfort that has been widely used (Borg, 1973; Noble, Metz, Pandolf, Bell, Cafarelli, and Sime, 1973; Skinner, Hutsler, Bergstrinova, and Buskirk, 1973) is a scale developed by Borg (1962) to measure subjective

ratings of perceived exertion (RPE). Perceived exertion has been defined as one's subjective rating of the intensity of work being performed.

Borg (1985) concludes that humans have a well-developed capacity for perceiving exertion. Perception of exertion is a simple measure of exercise intensity often used as a complement to physiological measurements such as heart rate (HR). A number of studies (Borg, 1962; Borg, 1967; Frankenhaeuser, Post, Nordheden, and Sjoeberg, 1969; Skinner, Borg, and Buskirk, 1970; Borg, 1985) have reported correlations of .80 and above between RPE and heart rate; this indicates that the subjective estimate of perceived exertion increases with successive increments in heartbeat frequency. The subjective feeling of exertion can serve as an important alternative to the objective measures when considering the relative strain on an individual. Borg states that the perception of exertion is, in many cases, as reliable and relevant as physiological measures.

The present research was part of a larger study to evaluate several microclimate cooling systems for potential use by combat forces participating in Desert Storm. The objectives of this study were to evaluate whether a cooling suit would lower subjective RPE, lower HR, and whether wearing a cooling suit would reduce the magnitude of the correlation between RPE and HR. To address these objectives, subjects were tested during exercise, wearing chemical defense ensemble, under four different combinations of ambient heat level and exercise intensity conditions.

METHODS

Participants:

Thirty-one U.S. Marine Corps volunteers served as subjects. Age range of the subjects was 18 to 30, with a mean age of 22 years. Subjects were not acclimatized to heat; they were experienced in the use of the chemical defense ensemble. Prior to participation, each subject was given a general medical screening that included a resting electrocardiogram reviewed by the attending physician.

Measures:

Heat Measures. A measure of thermal stress, used in both military and civilian applications, is the Wet Bulb Globe Temperature (WBGT) index. WBGT was obtained with an electronic meter that independently measures the dry bulb, wet bulb, and globe temperatures. The instrument displays each of these values as well as computes and displays the WBGT index in degrees Fahrenheit (NAVMED-P-5010-3, 1988).

Physiological Measures. A variety of physiological measures (HR, core temperature, skin temperature at various sites, blood pressure, urine volume and specific gravity, and blood constituent analyses) were taken during experimental sessions. Assessment of the cooling suit effect on physiological measures other than heart rate are beyond the scope of this study and therefore will be addressed in subsequent technical reports.

Materials:

Microclimate cooling was provided by a portable active ice system, EXOTEMP CD-22. This system, worn as an undergarment and weighing 9 pounds, consisted of liquid-cooled pants, shirt, and hood (see Figure 1). A backpack carried a frozen water bottle, a 290 ml/min Carlson pump, and a battery. Water was circulated between the frozen bottle (replaced every 40 min) and the series of tubes that run through the undergarment.

Figure 1. Liquid-cooled EXOTEMP CD-22 microclimate system.

Procedure:

Four groups of eight subjects were assigned to one of four different experimental conditions. Subjects were tested on separate days in control and cooling suit sessions, one-half of the subjects had their cooling suit session on the first day and one-half of the subjects had their control session on the first day. The four different combinations of ambient heat level and exercise intensity are described in descending order from the most strenuous to the least strenuous scenario.

In experimental Condition 1, hot temperature and hard exercise (120°HrdX), eight subjects were tested on two separate days during control and cooling suit sessions in a heat chamber at 120°F, 20% relative humidity (RH), on a 3.0 miles per hour (mph) treadmill walk at a 2% grade. In experimental Condition 2, warm temperature and hard exercise (90°HrdX), seven different subjects (one of the original eight subjects was unable to participate) were tested in separate control and cooling suit sessions at 90°F, 35% RH, at the same treadmill speed and grade as described in Condition 1. In experimental Condition 3, hot temperature and easy exercise (120°EsyX), eight more subjects were tested during control and cooling suit sessions with the chamber heated to 120°F, 20% RH, on a 1.8 mph treadmill walk at a 0% grade. In experimental Condition 4, warm temperature and easy exercise (90°EsyX), a group with eight subjects was tested in a control and a cooling suit session with the chamber heated to 90°F, 35% RH, on a 1.8 mph treadmill walk at a 0% grade.

During an experimental session the subject carried an M-16 rifle and wore a 31-lb backpack, water was provided ad libitum. Every 5 min the participant was asked for a subjective RPE on a scale of 6 to 20 (see Appendix A). Each subject continued walking on the treadmill until one of the following occurred: (1) subject expressed a desire to stop, (2) physician terminated the experiment, (3) rectal temperature reached 103° F, or (4) heart rate was 95% of predicted maximum for 5 min. These session-termination criteria resulted in different participation times for each subject; therefore, all subsequent statistical analyses were conducted on data from only the first 25 min of each control or cooling suit session.

Statistical Analysis:

Repeated measures multivariate analysis of variance (MANOVA) was used to determine if a statistically significant difference existed between the control and cooling suit sessions for RPE and HR during each of the four heat/exercise scenarios. In addition, Pearson correlations were computed between RPE and HR to measure the degree of relationship between the subjective measure and the physiological measure being simultaneously recorded. For the purpose of comparing the magnitudes of the calculated Pearson correlations for statistically significant differences, $\underline{r}$ to $\underline{t}$ transformations were performed.

RESULTS and DISCUSSION

The first evaluation made during this study was to determine whether wearing a cooling suit would lower RPE and HR during four different heat level/exercise intensity conditions. Table 1 shows the mean RPE and HR during each heat/exercise scenario. Subjects in the most strenuous experimental condition, 120°HrdX, reported statistically significantly lower RPE during the cooling suit session when compared to the control session ($\underline{F}$ [1,7] = 7.12, $\underline{p}$ = .032). Mean HR was also lower during the cooling suit session and the difference approached statistical significance ($\underline{F}$ [1,7] = 5.37, $\underline{p}$ = .054). During each of the three less strenuous experimental conditions (90°HrdX, 120°EsyX, 90°EsyX) RPE difference was not statistically significant between the cooling suit and control sessions. There was, however, a statistically significant lowering of HR during each of the cooling suit sessions. These results suggest that the use of a cooling suit will significantly lower RPE in very hot conditions during hard exercise, and that a cooling suit may not significantly lower perceived exertion under less severe heat/exercise conditions even when HR is significantly lower. As expected, mean RPE and mean HR were highest during the 120°HrdX control session, and both measures were lowest during the 90°EsyX cooling suit session. During the three less severe heat/exercise conditions, the fact that subjects did not perceive less exertion when HR was significantly lower, seems to suggest that wearing a cooling suit interfered with perception of exertion. Possibly the bulk of the cooling suit combined with the weight of the backpack eliminated perception of lower HR and therefore, perception of exertion. Further evidence for the conclusion that wearing the cooling suit

interfered with perception of exertion is revealed by the second evaluation made in this study. Pearson correlations were computed to examine the magnitude of the relationship between RPE and HR. Table 2 shows the Pearson correlations for each of the experimental sessions.

TABLE 1

Mean RPE and mean HR (beats per minute)
during each experimental session

Experimental Condition	Session	Mean RPE	Std. Dev.	Mean HR	Std. Dev.
120°HrdX (n=8)	Control	13.8	1.3	147	16.5
	Cooling suit	12.6 *	1.7	136 +	16.6
90°HrdX (n=7)	Control	12.5	2.2	144	5.9
	Cooling suit	12.8	1.3	135 *	6.1
120°EsyX (n=8)	Control	11.6	2.1	134	11.2
	Cooling suit	11.2	2.2	118 *	15.7
90°EsyX (n=8)	Control	11.4	1.8	111	25.4
	Cooling suit	11.1	2.4	103 *	19.9

+ Difference between means approaches statistical significance, *p* = .054

* Mean is statistically significantly lower at alpha level of .05

During control and cooling suit sessions in all four experimental conditions, RPE and HR were correlated in a positive direction. The magnitude of each RPE and HR correlation during cooling suit sessions was considerably lower than during the corresponding control session. In addition, _r_ to _t_ transformation analyses showed that the correlation in the cooling suit session was statistically significantly lower during three of the four experimental conditions. These results further corroborate the conclusion that wearing a microclimate cooling suit interfered with perception of exertion.

TABLE 2

Pearson correlation between RPE and HR during each experimental session

Experimental Condition	Session	Correlation
120°HrdX (n=8)	Control	.79
	Cooling suit	.66
90°HrdX (n=7)	Control	.92
	Cooling suit	.53 *
120°EsyX (n=8)	Control	.92
	Cooling suit	.57 *
90°EsyX (n=8)	Control	.82
	Cooling suit	.48 *

* Correlation is statistically significantly lower at alpha level of .05

A potential safety concern is raised by the finding that the cooling suit interfers with perception of exertion; could a person overexert while wearing the cooling suit? Results of the present study suggest that there is not a risk of overexertion because HR was significantly lowered by wearing the cooling suit. Further, mean HR's during each of the cooling suit sessions are well within the recommended safe limits of beats per minute during exercise.

CONCLUSIONS

During conditions of high heat and hard exercise, RPE was significantly lower for subjects wearing a microclimate cooling suit. Measured in beats per minute, mean HR was also lower during the cooling suit session when compared to the control session, and this difference approached statistical significance. Under less severe heat and exercise conditions, RPE was not significantly lowered by wearing a microclimate cooling suit; however, HR was statistically significantly lowered during cooling suit sessions. The magnitude of the Pearson correlation between RPE and HR was lower during sessions in which a microclimate cooling suit was worn. It appears that Borg's assertion that RPE is an acceptable substitute for physiological measures of exertion may need to be reexamined in conditions of exercise in heat when wearing a microclimate cooling suit. The observed decrease in the magnitude of Pearson correlations between RPE and HR indicate that a cooling suit will interfere with subjective perception of exertion. This finding is not reason for safety concern because HR was significantly lowered during cooling suit sessions. During each of the four heat and exercise combinations in which a cooling suit was worn, mean HR's did not exceed the recommended safe number of beats per minute during exercise.

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APPENDIX A

<u>Ratings of Perceived Exertion Scale</u>

6

7 VERY VERY LIGHT

8

9 VERY LIGHT

10

11 LIGHT

12

13 SOMEWHAT HARD

14

15 HARD

16

17 VERY HARD

18

19 VERY VERY HARD

20

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13. ABSTRACT *(Maximum 200 words)*

Operation Desert Storm demonstrated a need for individual microclimate cooling during strenuous activity. Evaluation of a cooling system should not only consider physiological functions but subjective measures of comfort, such as ratings of perceived exertion (RPE). The objectives of this study were to evaluate a cooling suit's effect on: (a) subjective RPE, (b) heart rate (HR), and (c) the magnitude of the correlation between RPE and HR. Thirty-one U.S. Marine Corps subjects, wearing chemical defense ensemble, were tested in four separate scenarios of heat/exercise combinations during both cooling suit and control sessions. Results of repeated measures multivariate analysis of variance showed that RPE was significantly lowered by wearing a cooling suit during only the most strenuous of the four heat/exercise scenarios; however, HR was lower during the cooling suit sessions in all four scenarios. A decrease in the magnitude of the correlation between RPE and HR during all four cooling suit sessions indicated that a microclimate cooling suit interfered with perception of exertion.

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